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Shadowing Aspects of Nuclear Parton Distributions

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Abstract

Various shadowing aspects of nuclear parton distributions are discussed in a parton-model framework. We explain existing x dependent data of F_2^A/F_2^D, then the model is applied to a flavor asymmetry $\bar{u}-\bar{d}$ in a nucleus, to shadowing in valence-quark distributions, and to nuclear dependence of Q^2 evolution. First, we find that a finite nuclear $\bar{u}-\bar{d}$ distribution could be possible due to nuclear interactions even in the flavor symmetric case in the nucleon ($\bar{u}-\bar{d}$=0). Second, it is indicated that valence-quark shadowing could be used for discriminating among various shadowing models. Third, we find that nuclear dependence of Q^2 evolution $\partial[F_2^{Sn}/F_2^C]/\partial[\ln Q^2]$, which was found by NMC, is essentially understood by modification of parton distributions in nuclei. However, higher-twist effects in nuclear interactions could be tested by studying the details of the nuclear Q^2 evolution.

1. Introduction: structure function $\mathbf{F_2}$ in nuclei

Nuclear modification of the structure function F_2 has been investigated extensively. In recent years, it became possible to measure the ratio F_2^A/F_2^D in the "shadowing" region, namely at small x. Accurate experimental data make it possible to test the details of theoretical shadowing models. Among various models for describing F_2, we study a hybrid parton model with Q^2-rescaling and parton-recombination mechanisms [1]. The rescaling model was originally proposed by considering possible confinement-radius changes in nuclei. Although there is still such a possibility of the nucleon-size modification, the major part of the EMC effect at medium x could be explained by the nuclear binding. In order to understand the seemingly different ideas, Close, Roberts, and Ross claim that it is possible to relate two pictures by using factorization-scale independence [2]. In calculating a nuclear structure function in the operator product expansion, we separate it into two pieces depending on short and long distance physics. This separation scale, which is called the factorization scale, is an arbitrary constant and a physical observable should not depend on it. The various interpretations correspond to different choices of the factorization scale. Therefore, we may view the rescaling explanation as an alternative way of explaining the EMC effect to the binding explanation rather than as a different one.

In the small x region, we use the parton-recombination mechanism for describ-

ing the shadowing. The longitudinal localization size of a parton exceeds the average nucleon separation in a nucleus at $x < 0.1$. It means that partons in different nucleons could interact in the nucleus, and the interaction is called parton recombination. Its contribution is a higher-twist effect which is proportional to α_s/Q^2. In order to explain x dependence of F_2^{Ca}/F_2^D measured by NMC, it is necessary to take rather small Q^2 (Q_0^2 =0.8 GeV^2) if the KMRS-B type distributions are chosen as input ones. The rescaling and recombination mechanisms are used for calculating nuclear parton distributions at Q_0^2. Then, they are evolved to those at larger Q^2.

We show theoretical results for x dependence of the ratio F_2^{Ca}/F_2^D [1] together with experimental data. In Fig. 1, the solid curve shows theoretical results at Q^2=5 GeV^2. They are compared with experimental data by NMC and SLAC [3]. We obtain good agreement with the data if Q_0^2 is adjusted to a small value (0.8 GeV^2). The model explains the modification at small x (< 0.05) and at large x (> 0.8) in terms of the recombinations, the depletion at medium x by the rescaling, and the antishadowing at $x \approx 0.2$ by competition between two mechanisms. We find that our parton model can explain the NMC data F_2^A/F_2^D, so that the model is applied to other interesting topics in the following sections.

2. Flavor asymmetric distribution $\bar{\mathbf{u}} - \bar{\mathbf{d}}$ in nuclei

NMC suggested that the Gottfried sum rule should be violated in 1991. Since then, there have been efforts to investigate mechanisms of creating a flavor asymmetric distribution $\bar{u}-\bar{d}$ in the nucleon. In order to test the NMC finding, Drell-Yan experiments for the proton and the deuteron are in progress at Fermilab. On the other hand, there exist Drell-Yan data for various nuclear targets, so that some people use, for example, tungsten data for investigating the flavor asymmetry. However, we have to be careful in comparing the NMC results with the tungsten data because of possible nuclear medium effects. In order to find whether such comparison makes sense, we estimate a nuclear modification effect. It in turn could be found experimentally by analyzing accurate Drell-Yan data in the near future.

We investigate the $\bar{u}-\bar{d}$ distribution in the tungsten nucleus [4]. If isospin symmetry could be applied to parton distributions in the proton and the neutron, the distribution per nucleon becomes $x[\bar{u}(x) - \bar{d}(x)]_A = -\varepsilon x[\bar{u}(x) - \bar{d}(x)]_{proton}$ without considering nuclear modification. It is just the summation of proton and neutron contributions. The neutron-excess parameter ε is defined by $\varepsilon = (N-Z)/(N+Z)$, and it is 0.196 for the tungsten ${}^{184}_{74}W_{110}$. According to the above equation, the flavor distribution should be symmetric ($[\bar{u} - \bar{d}]_W = 0$) if it is symmetric in the nucleon. However, it is not the case in the recombination model. In a neutron-excess nucleus ($\varepsilon > 0$) such as the tungsten, more $\bar{d}$ quarks are lost than $\bar{u}$ quarks are in the parton recombination process $\bar{q}q \longrightarrow G$ in Fig. 2 because of the d quark excess over u in the nucleus. In the case of $\bar{u} - \bar{d}$=0 in the nucleon, only $\bar{q}q \longrightarrow G$ processes contribute. If it is not symmetric in the nucleon $[(\bar{u} - \bar{d})_N \neq 0]$, $\bar{q}G \rightarrow \bar{q}$ type contributions become dominant. The

flavor asymmetry is given by $x[\Delta\bar{u}(x) - \Delta\bar{d}(x)]_A = -(w_{nn} - w_{pp})x[\Delta\bar{u}(x) - \Delta\bar{d}(x)]_{pp}$, where w_{nn} and w_{pp} are neutron-neutron and proton-proton combination probabilities ($w_{nn} - w_{pp} = \varepsilon$). $[\bar{u}(x) - \bar{d}(x)]_{pp}$ is the asymmetry produced in the proton-proton combination. Detailed equations of the recombination effects are given in Ref. [4].

We evaluate the recombination contributions with the input parton distributions MRS-D0 (1993) at Q^2=4 GeV^2. In the $(\bar{u} - \bar{d})_N = 0$ case, $\Delta = 0$ is taken in the MRS-D0 distribution. Obtained results are shown in Fig. 3, where the solid (dashed) curve shows the $x[\Delta\bar{u} - \Delta\bar{d}]_A$ distribution of the tungsten nucleus with the flavor symmetric (asymmetric) sea in the nucleon. In the $(\bar{u} - \bar{d})_N = 0$ case, the positive contribution at small x can be understood by the processes in Fig. 3. In the $(\bar{u} - \bar{d})_N \neq 0$ case, the $\bar{q}(x)G \to \bar{q}$ process is the dominant one kinematically at small x. Its contribution to $\bar{q}(x)$ is negative because $\bar{q}$ with momentum fraction x is lost in the recombination process. However, more $\bar{d}(x)$ is lost than $\bar{u}(x)$ is because of the $\bar{d}$ excess over $\bar{u}$ in the proton ($[\Delta\bar{u} - \Delta\bar{d}]_{pp} > 0$). Therefore, the overall contribution becomes negative in $[\Delta\bar{u}(x) - \Delta\bar{d}(x)]_A$ due to the neutron excess as shown in Fig. 3. In the medium x region, the $\bar{q}G \to \bar{q}(x)$ process becomes kinematically favorable. Because it produces $\bar{q}$ with momentum fraction x, its contribution becomes opposite to the one at small x. The above results are obtained at Q^2=4 GeV^2. Considering the factor of two coming from the Q^2 dependence, we find that the nuclear modification is of the order of 2%–10% compared with the asymmetry suggested by the MRS-D0 distribution.

[**Summary**] We find that finite flavor asymmetric distributions are possible in nuclei ($[\bar{u}(x) - \bar{d}(x)]_A \neq 0$) even in the symmetric case in the nucleon ($[\bar{u}(x) - \bar{d}(x)]_N = 0$). According to the recombination model, the nuclear effects on $[\bar{u}(x) - \bar{d}(x)]_A$ are of the order of 2%–10% compared with the one estimated by the NMC flavor asymmetry in the nucleon. Because the Drell-Yan experiments on proton, deuteron, and nuclear targets will be completed at Fermilab in the near future, it is possible in principle to study the nuclear modification experimentally.

3. Valence-quark shadowing

It is shown in section 1 that the parton-recombination model explains the F_2 shadowing fairly well if small Q_0^2 is taken. However, it is not the only shadowing explanation. There exist other models which produce similar results on the F_2 shadowing. We may discriminate among various models by predicting unobserved quantities. Gluon shadowing [5] should be an interesting one for future theoretical and experimental studies. As another possible quantity for testing the models, we discuss valence-quark shadowing in this section [6]. We show that it depends much on theoretical ideas by using two different shadowing models. The first one is the recombination model with Q^2 rescaling in section 1. The second is an aligned-jet model [7], which is an extension of the vector-meson-dominance (VMD) model.

The first model prediction is the following. The rescaling produces depletion in the ratio $R_3 \equiv V_A/V_D$ at medium x as it explains the original EMC effect. Because the

rescaling satisfies the baryon-number conservation, the ratio R_3 becomes larger than unity at small x. Parton-recombination contributions are rather contrary to those of the rescaling. The recombinations decrease the ratio at small x and increase it at medium and large x. The overall contributions are shown in Fig. 4 by a solid curve (model 1). Antishadowing is obtained in this model instead of the shadowing in F_2. This difference is caused by the fact that the rescaling is used only for the valence-quark distribution and not for sea-quark and gluon distributions.

In the aligned-jet model, the virtual photon transforms into a $q\bar{q}$ pair, which then interacts with the target. However, the only $q\bar{q}$ pair aligned in the direction of γ interacts in a similar way to the vector-meson interaction with the target. The propagation length of the hadronic ($q\bar{q}$) fluctuation exceeds the average nucleon separation in a nucleus at small x, so that the shadowing phenomena occur due to multiple scatterings. In this model, vector-meson-like $q\bar{q}$ pairs interact with sea quarks and valence quarks in the same manner. Therefore, the valence-quark shadowing is very similar to the F_2 one as shown in Fig. 4 by a solid curve (model 2) [7]. The shadowing is calculated by the aligned-jet model at small x, then the curve is extrapolated into the medium x region simply by using the baryon-number conservation. It is interesting to find completely different shadowing results in models 1 and 2.

Next, we investigate whether both results are allowed by existing experimental data. There are neutrino data for the deuteron and for nuclei; however, the accuracy is not good enough to test the nuclear modification particularly in the small x region. Instead, we use existing F_2^A/F_2^D data and the baryon-number conservation. We assume that V_A/V_D is the same as F_2^A/F_2^D in the region $x \geq 0.3$ because F_2 is dominated by valence-quark distributions. The SLAC F_2^{Ca}/F_2^D data [3] at $x > 0.3$ are fitted by a smooth curve in Fig. 4, then it is extrapolated into the small x region by considering the baryon-number conservation. Because there is no guideline for the extrapolation, a straight dashed-line is simply drawn in Fig. 4. As another possibility, the curve is smoothly extrapolated by allowing about 6% antishadowing at $x = 0.1 - 0.2$ (dotted curve). The hatched area between the line and the curve is roughly the region, which is allowed by the current experimental data. The figure indicates that both results are allowed by the experimental data at this stage.

[**Summary**] The valence-quark shadowing is investigated in two different models: the parton-recombination with Q^2 rescaling and the aligned-jet model. Both shadowing results are completely different, so that they can be tested by accurate experimental measurements. However, both theoretical results are allowed by the existing experimental data at this stage. The shadowing could be studied at HERA in future by observing charged pion productions [8]; hence, there is a good possibility of discriminating among various shadowing models by studying the valence-quark distributions.

4. Nuclear dependence of Q^2 evolution

The x dependence of nuclear modification in the structure function F_2 has been

accurately measured and it is well studied theoretically. On the contrary, there is little investigation on Q^2 dependence partly because experimental accuracy was not good enough to find nuclear dependence of Q^2 evolution. However, it becomes possible to find the details of nuclear Q^2 evolution due to recent NMC analysis of tin and carbon F_2 ratios [9]. They found significant deviations $\partial[F_2^{Sn}/F_2^C]/\partial[\ln Q^2] \neq 0$, so that it is an interesting topic for theoretical studies.

Q^2 dependence of structure functions can be calculated by using the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) equations. In addition, parton-recombination (PR) contributions are expected at small x. Although the DGLAP equations are well tested by various experimental data, the PR equations are not well established yet. There are two possible sources for the nuclear dependence in the evolution equations. One is nuclear parton distributions, and the other is the recombination effects. As it is discussed in sections 1, 2, and 3, parton distributions are modified due to nuclear medium effects. The modifications affect the Q^2 evolution through splitting functions. Because parton-recombination probability is proportional to $A^{1/3}$, which is the number of nucleons in the longitudinal direction, the recombination effects could become significant in large nuclei. We study these two nuclear contributions [10] in comparison with the NMC data for $\partial[F_2^{Sn}/F_2^C]/\partial[\ln Q^2]$.

As the input parton distributions in tin and carbon nuclei, we employ those in section 1 [1]. They are evolved by leading-order (LO) DGLAP, next-to-leading-order (NLO) DGLAP, and PR equations with the help of the computer program bf1.fort77 in Ref. [11]. Three evolution results are shown at Q^2=5 GeV^2 together with the preliminary NMC data [9] in Fig. 5. The DGLAP results agree with the experimental tendency; however, the PR curve is well below the data points at small x. The disagreement between the PR results and the NMC data does not mean the PR mechanism is in danger. The large discrepancy is caused first by the choice of initial Q^2 (Q_0^2=0.8 GeV^2) and second by the choice of the constant K_{HT}=1.68 in a higher-dimensional gluon distribution. Although the value of K_{HT} is taken according to the Qiu's numerical analysis, it is not a uniquely determined quantity. In order to discuss the validity of the parton recombination effects, we have to estimate K_{HT} theoretically. From Fig. 5, we can at least rule out large recombination contributions. Because the figure indicates significant recombination effects, the Q^2 derivative could be used for examining such contributions.

[Summary] The NMC's nuclear Q^2 dependence, $\partial[F_2^{Sn}/F_2^C]/\partial[\ln Q^2] \neq 0$, could be essentially understood by ordinary Q^2 evolution equations together with modified nuclear parton distributions. Because the PR evolution results disagree with the data, *large* higher-twist effects from the parton recombinations could be ruled out. However, it is encouraging to study the details of the recombination mechanism in comparison with the NMC data.

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to similar topics on the nuclear structure functions and on the flavor asymmetry.

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References

[1] S. Kumano, Phys. Rev. C48 (1993) 2016; C50 (1994) 1247.

[2] F. E. Close, R. G. Roberts, and G. G. Ross, Nucl. Phys. B296 (1988) 582.

[3] P. Amaudruz et al. (NMC collaboration), Nucl. Phys. B441 (1995) 3; J. Gomez et al. (SLAC-E139 collaboration), Phys. Rev. D49 (1994) 4348.

[4] S. Kumano, Phys. Lett. B342 (1995) 339.

[5] S. Kumano, Phys. Lett. B298 (1993) 171.

[6] R. Kobayashi, S. Kumano, and M. Miyama, Phys. Lett. B354 (1995) 465.

[7] L. L. Frankfurt, M. I. Strikman, and S. Liuti, Phys. Rev. Lett. 65 (1990) 1725.

[8] S. Kumano, nucl-th/9510029.

[9] A. Mücklich and A. Sandacz (NMC), private communications on the NMC preliminary data for $\partial[F_2^{Sn}/F_2^C]/\partial[\ln Q^2]$.

[10] S. Kumano and M. Miyama, hep-ph/9512244.

[11] M. Miyama and S. Kumano, hep-ph/9508246, Comput. Phys. Commun. in press; R. Kobayashi, M. Konuma, and S. Kumano, Comput. Phys. Commun. 86 (1995) 264.

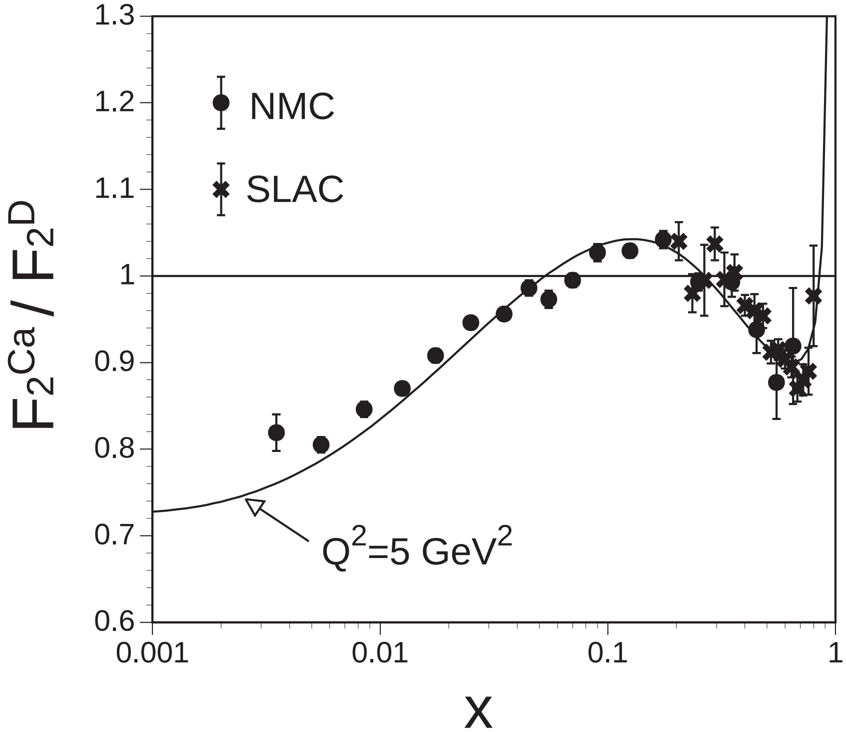

Fig. 1 x dependence of F_2^{Ca}/F_2^{D}.

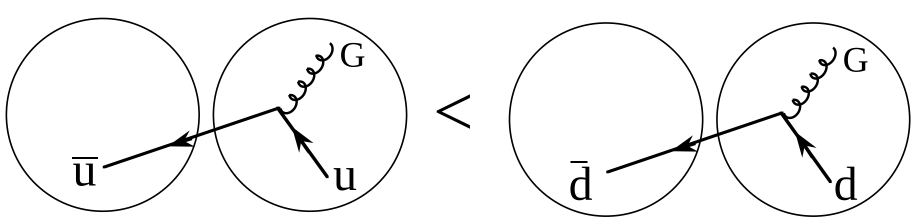

Fig. 2 Parton recombinations.

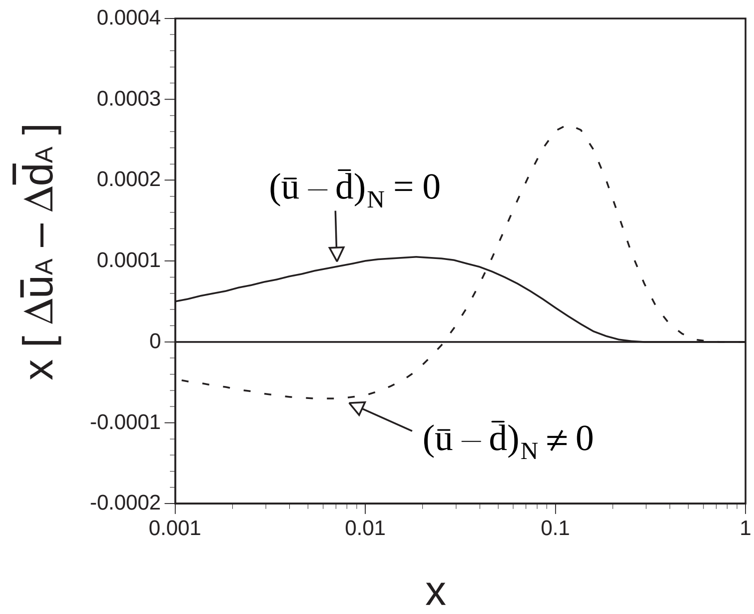

Fig. 3 Flavor asymmetry in W.

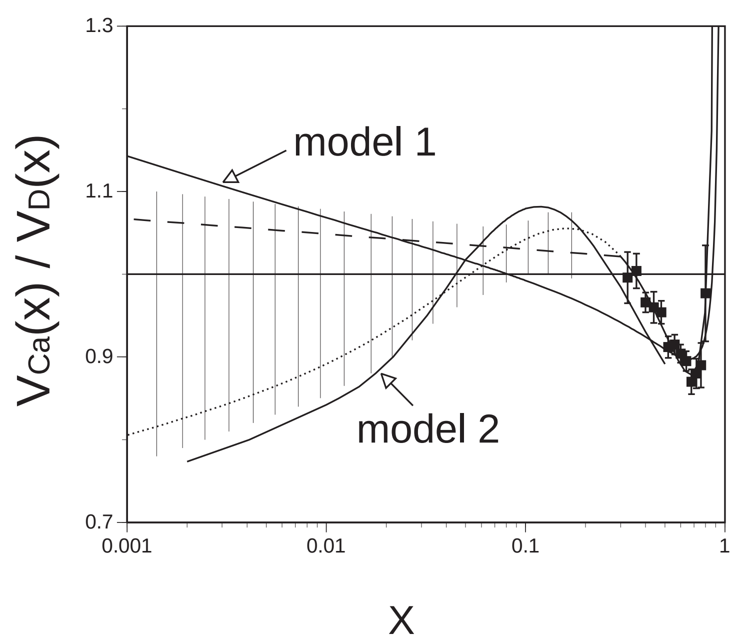

Fig. 4 Valence-quark “shadowing”.

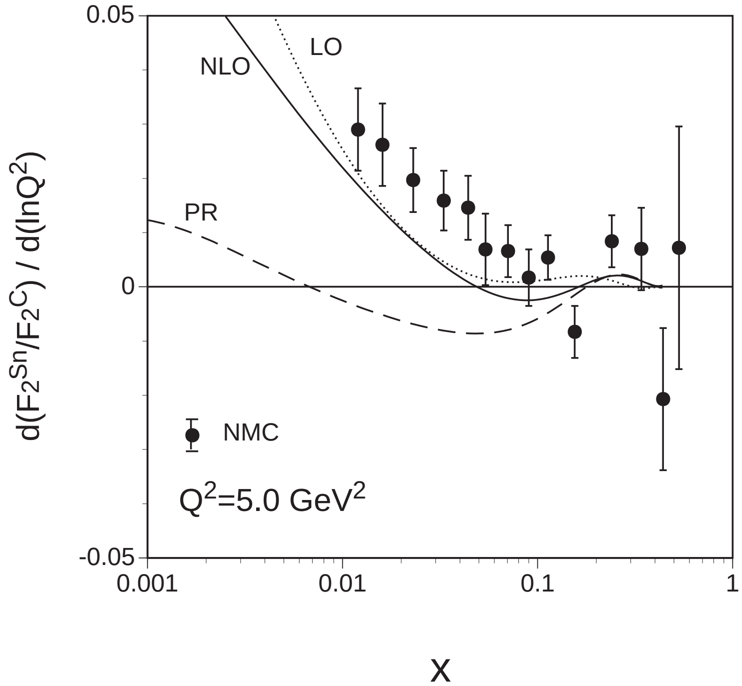

Fig. 5 Nuclear Q^2 evolution.